EXPERIMENTER'S CORNER

By Forrest M. Mims

Experimenting with Piezoelectric Devices

Part 2. Piezo-Alerters and Crystal Oscillators

WE experimented with piezoelectric spark generators, microphones, and filters in Part 1 of this two-part series on piezoelectric devices. This month, we'll discuss using piezoelectric alerters and quartz-crystal oscillators.

Piezoelectric Alerters. Crystal microphones and speakers are designed to operate across a wide band of audio frequencies. Piezoelectric alerters, however, are generally designed to operate at a fixed or relatively narrow audio-frequency band. They are true solid-state sound sources.

As far as I know, the first commercial piezo-alerter was the Mallory Sonalert®. Sonalerts are available in various kinds of housings having a range of audio outputs. Most include self-contained drive circuitry.

I first purchased a Sonalert in 1966 and a few years later used it to measure the velocity of a model rocket in flight. The Sonalert, a Model SC628 emitting a tone of 2.9 kHz, was installed in the base of a model rocket. The rocket's engines were installed in pods attached to its center tube. The sound from the Sonalert was tape recorded from the ground during the rocket's flight. By measuring the doppler shift, it was possible to determine the rocket's velocity.

Alerter Construction and Operation. Thanks to their miniature size, low current consumption, and penetrating sound, piezoelectric alerters are commonly used in digital watches, clocks, smoke alarms, pagers, appliances, calculators and games. A typical alerter is a metal disc from 25 to 40 mm in diameter upon which is bonded a smaller disc of piezoceramic material. A conductive film is deposited over the ceramic layer, and electrodes are attached to it and the metal disc.

Often alerter discs include a *feedback electrode* made by isolating a small section of the metal film on the back of the piezoceramic material. The feedback electrode, which is shown in Fig. 1, simplifies the design of driver circuits and stabilizes the alerter's oscillation frequency. Piezo-alerter discs can be purchased alone or installed in plastic holders complete with connection leads. Versions with self-contained driver circuits much like the Mallory Sonalert are now available from several companies.

It is essential to properly mount an alerter disk for maximum sound output. If the vibrating portion of the disk is cemented or otherwise attached to a mount, severe attenuation of the device's sound output will occur.

Figure 2 shows three acceptable ways to mount an alerter disc. The *center mount* permits the outer rim of the disc to vibrate, while the *edge mount* permits the entire disc to vibrate. Both of these methods permit the disc to vibrate across a range of audio frequencies.

The *nodal mount*, also shown in Fig. 2, is best for a very-loud, single-frequency tone. The node of a piezo-alerter disc is a concentric ring around the center of the disc at which vibration at a fixed frequency is at a minimum (or even non-existent). Ideally, the diameter of the nodal ring is 0.55 times the diameter of the metal disc. The actual diameter, however, varies from the predicted value due to the presence of the piezoceramic disc and nonuniformities in the metal disc.

One way to find the actual location of the nodal ring is to sprinkle fine sand or powder on a piezo-alerter disc being driven at a desired frequency by a suitable oscillator. The powder particles will gradually bounce into the nodal region and form a thin, circular ring around the center of the disc.

Piezo-Alerter Driver Circuits. A piezo-alerter can be driven directly by a variable-frequency signal generator. Even alerters having nodal-mounted discs can be operated across the audio spectrum, although edge- and center-mounted discs work best across a wide band of audio frequencies.

Figure 3 shows a simple, single-transistor driver for a piezo-alerter having a feedback terminal such as the model PKM11-6A0 from muRata Corporation of America (1148 Franklin Rd., SE, Mariette, GA 30067). This alerter is also available from Radio Shack (catalog number 273-064).

The PKM11-6A0 can be operated over a specified range of 3 to 15 V (mine works down to 1 V) and has a current consumption over this range of 2 to 12 mA. Its output sound-pressure level ranges from more than 80 dB at 3 V to more than 90 dB at 15 V. Its resonant frequency is within 700 Hz of 6.5 kHz. It has an operating temperature range of − 20° to + 60° C and weighs only 1.5 grams.

A test version of the circuit in Fig. 3 drove the alerter at a frequency of 6772 Hz when V_{CC} was 3 V. This frequency is controlled by the dimensions of the feedback tab on the alerter disc and not the components of the oscillator. For example, changing *R1* over a range of 100 to 330 kilohms altered the shape of the waveform but not the frequency. The frequency is nearly independent of changes in V_{CC}.

Figure 4 shows a simple, single-chip, CMOS oscillator suitable for driving a piezo-alerter. This circuit is adapted from one in a Gulton Industries application note. Notice how the 4049

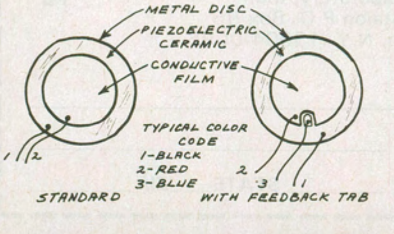

Fig. 1. Piezoelectric alerter elements.

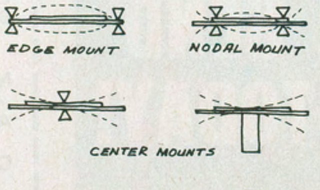

Fig. 2. Three mounting arrangements for piezoelectric alerter elements.

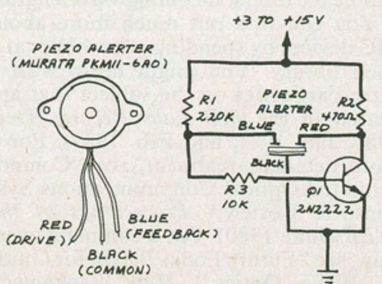

Fig. 3. Piezoelectric alerter driver circuit.

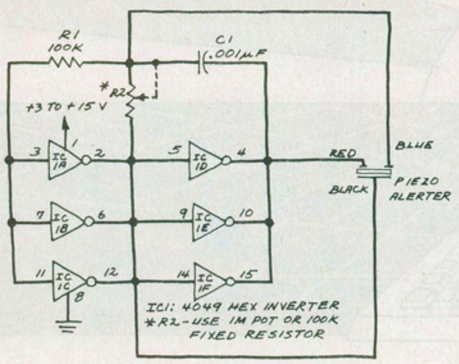

Fig. 4. An IC alerter driver circuit.

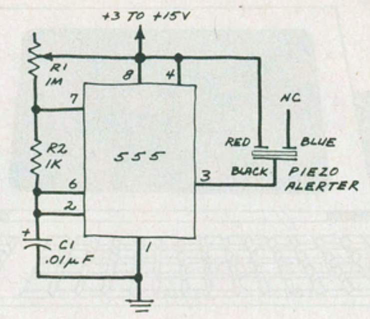

Fig. 5. Adjustable-frequency driver circuit.

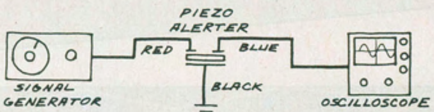

Fig. 6. Using a piezoelectric alerter as a signal filter.

gates are connected in parallel to permit higher drive current.

The circuit in Fig. 4 has the advantage of having an adjustable frequency. A breadboard version I built operated over a range of about 185 Hz to 7 kHz. The frequency change, however, was not gradual but occurred in steps. When the piezo-alerter reached its resonant frequency of around 7 kHz, changing *R2*'s resistance had no effect.

The circuit in Fig. 5 will drive piezo-alerters with and without feedback terminals at a variable frequency. Unlike the circuit in Fig. 4, this circuit provides a gradual, nonstepped output tone. A slow *pock . . . pock . . . pock* sequence can be produced by using a 0.47-µF capacitor for *C1*.

The operation of a piezo-alerter's feedback electrode can be graphically demonstrated by connecting the anode of a red LED to the blue lead of the alerter in Fig. 5. Connect the LED's cathode to ground. The output from the blue lead easily exceeds a few volts, more than enough to forward-bias the LED and cause it to emit a dim glow.

Keep in mind that there is no electrical connection between the feedback electrode and the main electrode on the piezoelectric ceramic disk. The voltage at the feedback terminal is true piezoelectricity. It is generated in response to the pressure wave that appears in the piezoelectric ceramic disk. (The pressure wave is generated in response to the drive signal.) The LED demonstration shows how a piezoelectric device can function as a solid-state transformer or isolator.

Using an Alerter as a Filter. Figure 6 shows how to demonstrate the use of a piezo-alerter as a ceramic filter. The model PKM11-6A0 exhibited frequency-response peaks at 2.3 kHz, 7.0 kHz, 18 kHz, 27 kHz and 45 kHz. While a scope is helpful, it's possible to monitor the filter's operation by simply listening to the change in amplitude of the filter's sound output as the signal generator's frequency is varied. Of course this method only works at audio frequencies.

Incidentally, I attempted to measure the delay introduced by the piezoelectric ceramic with the help of a dual-trace 100-MHz oscilloscope. The speed of sound in the ceramic is around 5000 m/s according to *Reference Data for Radio Engineers* (ITT, Howard W. Sams & Co., 1975, p. 4-44). Since the gap between the main and feedback electrodes on the piezo-alerter disc is 0.5 mm, the expected delay is 100 nanoseconds.

Though the driver circuit for the test, the 555 oscillator in Fig. 5, provided clean leading- and trailing-pulse edges, the signal elicited from the feedback terminal had too much ringing for an accurate measurement of the delay. While I *think* I monitored a 100-ns delay, I cannot be certain due to the sloppy appearance of the feedback pulse. Perhaps you will have better results.

Other Alerter Ideas. The very narrow audio spectrum produced by piezo-alerters makes them ideal for use in experiments with sound. With the help of a microphone and an oscilloscope, you can easily demonstrate constructive and destructive interference of sound waves. Try pointing the microphone at the alerter while moving the microphone back and fourth. Or point both the alerter and the microphone at a flat metal or plastic panel which you can move back and forth. The proper arrangement will reveal a periodic amplitude fluctuation in the received signal, which you can view on the scope.

Note that, in an enclosed room, the sound of an alerter can vary dramatically in intensity. This is a result of the way the single-frequency acoustical waves from the alerter form complex interference patterns. Negative interference causes the formation of *dead spots* where the sound is virtually imperceptible. Constructive interference forms regions where the sound is uncomfortably shrill.

Sounds from radios, televisions, phonographs and people span a wide range of audio frequencies. Therefore, the effects of interference are not nearly as noticeable.

The effects of the acoustical interference caused by the pure tone emitted by an alerter may or may not be desirable. It is certainly attention getting to walk by an alerter and notice the changes in sound intensity. But it can also be confusing, particularly if you are trying to find the source of the sound in an enclosed room having many flat, hard reflecting surfaces! The resultant interference problems can be avoided by using multiple or swept tone alerters.

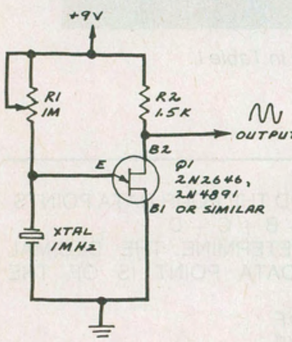

Fig. 7. UJT oscillator.

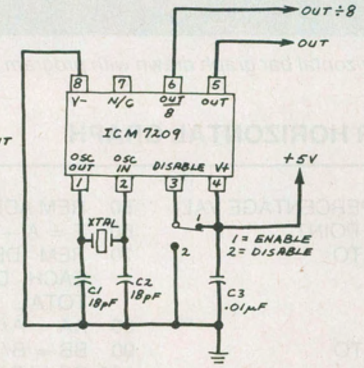

Fig. 8. Clock-pulse generator.

If you enjoy experimenting, try using a piezo-alerter as a microphone. You'll find that alerters with nodal mounting function as *frequency selective* sound detectors. Also, try adding a tube or reflector to an alerter to form a directional sound source. You can try operation at resonant ultrasonic frequencies. You can even develop various kinds of sonic radar circuits or try operating an alerter under water.

Alerter Precautions. Data sheets for piezo-alerters note that mechanical shock can cause them to generate high-voltage spikes that can damage their drive circuit and perhaps other associated circuits. This problem can be alleviated by installing an appropriately rated protection diode directly across the alerter.

Another precaution concerns the placement of an alerter on a circuit board. Be sure to mount the alerter on a rigid, fixed portion of the board. If the alerter is mounted on a cantilevered portion of a circuit board, it may set up vibrations in the board, substantially reducing its sound output.

Finally, a precaution I've *not* seen in the data sheets concerns the shrill sound which can be produced by some alerters. I've found that the sound can easily produce a piercing headache. While experimenting with the circuits described above, I eventually resorted to covering the aperture of the alerter with clay or tape to muffle the sound output.

Quartz-Crystal Oscillators. The final piezoelectric device we will consider is the quartz-crystal oscillator. Precision-cut wafers of quartz are used to make piezoelectric resonators having exceptional frequency stability. Figure 7 shows an ultra-simple, crystal-controlled, unijunction-transistor oscillator that uses only four components. The quartz crystal replaces a capacitor normally used in this circuit. The oscillation frequency can be tuned from about 50 kHz to exactly 1 MHz when the crystal has a resonant frequency of 1 MHz. Tuning is accomplished by altering the resistance of *R1*.

If you monitor the output of the oscillator in Fig. 7 with an oscilloscope, you will notice that the oscillation frequency tends to change in jumps as *R1* is adjusted. This is a result of the crystal's oscillating at various harmonics of its 1-MHz resonant frequency. Near 1 MHz, the oscillator quickly locks onto the crystal's resonant frequency.

The circuit in Fig. 7 is useful for understanding the operation of a simple quartz-crystal-controlled oscillator. It can also be used to supply a marker frequency to calibrate oscilloscopes, signal generators, and shortwave receivers.

Figure 8 shows a very useful crystal-controlled, clock-pulse generator. The circuit is designed around Intersil's ICM7209, a CMOS general-purpose timer chip. The crystal can be any quartz crystal having a resonant frequency of 10 kHz to 10 MHz. The circuit consumes only about 11 mA when powered by a 5-V supply and requires only four external components. ◇